HYDRODYNAMICAL INSTABILITY OF EXTRAGALACTIC STRATIFIED JETS

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1. Introduction

A rather new view of extragalactic radio sources seems to come out from recent observational data. For instance, in the case of 3C273, comparison of optical and radio maps suggested the presence of an inner optical jet embedded in a slow moving radio cocoon (Bahcall et al, 1995). Furthermore new ways of combining radio data at different frequencies provided original information on the sources. In particular sheaths of emission with specific spectrum and polarization have been found around the jets in Cygnus A, 3C449, two wide-angle-tail and one CSS sources, suggesting that such kind of sheaths or envelopes are commonly present around extragalactic jets (Katz-Stone, Rudnick, 1994; Rudnick, Katz-Stone, 1996).

The question of the origin of envelopes around extragalactic jets is still open. They can just emanate from the inner jets as the result of particle diffusion or correspond to some entrainment of the external gas by the inner jets. Another possibility, suggested a few years ago in the context of two-component jet models (Smith, Raine, 1985; Baker et al, 1988; Sol et al, 1989; Achatz et al, 1990), is that they have been directly ejected from the central engines. Indeed such models proposed and analyzed the scenario where a fast beam (corresponding to the inner core of the jet) is ejected from the vicinity of the central black hole and a slower collimated outer wind (corresponding to the envelope) is emitted by all parts of the accretion disk.

Anyway, such envelopes likely modify the interaction of the jets with the ambient media in which they propagate, and a question which immediately occurs is that of the Kelvin-Helmholtz stability properties of such "core-envelope" or "stratified" jets.

2. Kelvin-Helmholtz instability of stratified jets

We have studied the linear stage of the Kelvin-Helmholtz instability of such composite stratified jets, in the plane parallel approximation (Hanasz, Sol, 1996). Jets are assumed to be made of an inner core of relativistic gas with a relativistic bulk velocity surrounded on both sides by a sheet of non-relativistic gas with slower bulk velocity, and embedded in the external ambient medium. There are therefore two types of interfaces, the internal interfaces between the core and the sheet, and the external ones between the sheet and the ambient medium. Transition layers at all interfaces are described in the vortex-sheet approximation. We perform a temporal stability analysis and perturb the initial hydrodynamical equilibrium for the three components (relativistic core and non-relativistic sheet and external medium). The dispersion relation is then obtained from the boundary conditions at the internal and external interfaces, namely equality of pressure and equality of transverse gas and interface velocities. It writes in compact form:

$$\frac{Z_s}{Z_c}\mathcal{E} = \coth\ ik_{c_\perp} \quad \text{for the symmetric solution}$$

and

$$\frac{Z_s}{Z_c}\mathcal{E} = \text{th}\ ik_{c_\perp} \quad \text{for the antisymmetric solution.}$$

Here $\mathcal{E}$ is the term due to the effect of the envelope (or sheet),

$$\mathcal{E} = \frac{1 + \mathcal{R}_{se} e^{2ik_{s_\perp}(R-1)}}{1 - \mathcal{R}_{se} e^{2ik_{s_\perp}(R-1)}} \ .$$

$R = R_s/R_c$ is the ratio of the sheet radius to the core radius, $k_{c_\perp}$ and $k_{s_\perp}$ the transverse wavenumbers in core and sheet, Z_c, Z_s and Z_e the complex normal acoustic impedances of core, sheet and external medium. $\mathcal{R}_{se}$ is the reflection coefficient at the external interface between sheet and ambient medium, defined as a function of the acoustic impedances by

$$\mathcal{R}_{se} = \frac{Z_e - Z_s}{Z_e + Z_s} \ .$$

The dispersion relation reduces to the case of a single jet in different limits, (i) when there is no reflection at the external interface ($\mathcal{R}_{se} = 0$, $\mathcal{E} = 1$), (ii) when the sheet becomes very thick ($R >> 1$) since the factor of $\mathcal{R}_{s_e}$ then

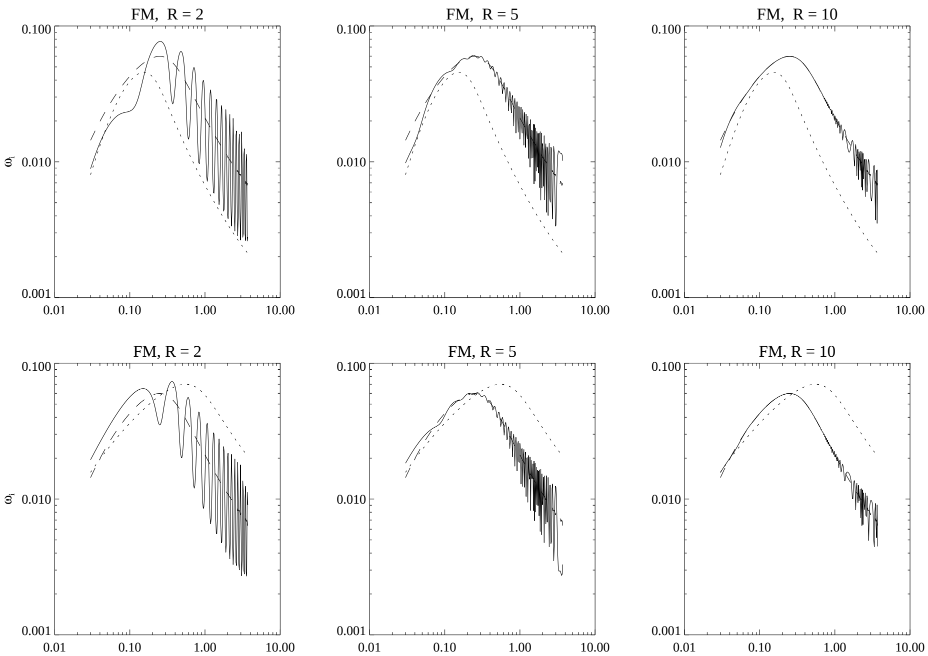

Figure 1. Examples of temporal growth rate of the instability versus the longitudinal wavenumber, for the fundamental mode of the antisymmetric solution. The thickness of the sheet increases from first ($R = 2$) to second ($R = 5$) and third ($R = 10$) columns. Upper case corresponds to underdense core and sheet, with density ratios $\rho_c/\rho_s = 0.01$ and $\rho_s/\rho_e = 0.1$ and lower case to a dense sheet with $\rho_c/\rho_s = 0.01$ and $\rho_s/\rho_e = 10$. Here the relativistic bulk Lorentz factor of the core is 10 and the Mach number of the sheet is zero. Dotted lines correspond to the solution without sheet ($R = 1$) and dashed lines to the solutions without external medium ($R \to \infty$, infinite sheet).

vanishes as $\exp[-2R\mathrm{Im}(k_{s_\perp})]$ and $\mathcal{E}$ tends to 1 again, (iii) when internal and external interfaces coincide ($R = 1$) and only the core and external gas components remain.

3. Results and interpretation

The dispersion relation has been solved numerically and various sets of parameters investigated. Figure 1 illustrates the temporal growth rate obtained in a few cases. The presence of the sheet generates an oscillating pattern due to the interferences of acoustic waves reflected at the boundaries of the sheet, namely at the internal and external interfaces.

The oscillating pattern can be explained as follows. The acoustic waves emitted at the internal interface are reflected at the external interface and come back to the internal one. The reflection coefficient for acoustic waves

at external interface $|\mathcal{R}_{se}|$ is smaller than 1, so there is no amplification of the wave amplitude there even if sheet is supersonic (this statement is valid for frequencies and wavenumbers typical for the core-sheet instability). The space between internal and external interfaces (i.e. the sheet itself) can be considered as the resonant cavity, which imposes the condition for resonance of the type

$$2L = n\lambda_s$$

and antiresonance

$$2L = \left(n + \frac{1}{2}\right)\lambda_s$$

where L is the distance between internal and external interfaces, and λ_s is the wavelength of the acoustic waves in the sheet, both of them are measured along the direction of propagation. The local maxima/minima of the value of growth rate correspond to the fulfillment of resonant/antiresonant condition. This is worth noticing that the resonant/antiresonant conditions are in general modified by an additional phase shift coming from the reflection at interfaces. The phase shift is dependent mostly on the density contrasts. This is apparent in figure 1 where the upper and lower rows represent two cases which differ only in the value of $\nu_s = \rho_s/\rho_e$ In the two cases the positions of maxima and minima are interchanged due to the mentioned phase shift. In all cases with thick enough sheet ($R > 1$) the solutions of the dispersion relation rapidly converge to the case of infinite sheet. So a sheet or envelope as thick as the inner core almost imposes the growth rate. Parameters of the envelope rather than those of the external medium appear to determine the Kelvin-Helmholtz instability, and the inner beam is somewhat isolated from the ambient gas. Relatively to the solution without envelope, the growth rate is increased for an envelope light compared to the external medium, and lowered for a dense envelope. So the presence of an heavy envelope can help to stabilize the jet configuration.

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